

Dr. Gregory Morscher
OAI at NASA Glenn Research Center
MS 106-5, Cleveland, OH 44135
Phone: (216) 433-5512 & Fax: (216) 433-5544
gmorscher@grc.nasa.gov

This image shows a single page of white paper with horizontal blue or grey ruling lines. The lines are evenly spaced and run across the width of the page. There is no handwriting or printed text on the page.

Acoustic Emission and Damage Monitoring During Fatigue of C- SiC Composites at Room Temperature

Gregory N. Morscher

Ohio Aerospace Institute (OAI)
NASA Glenn Research Center
Cleveland, OH

Chris Deemer

Argonne National Laboratory
Argonne, IL

Jacques Cuneo, Aron Smith, and

John Koenig

Southern Research Institute
Birmingham, AL

Objective

- To determine if an acoustic technique could be used to predict or sense eventual fatigue failure of C-SiC

Techniques Used

- Modal Acoustic Emission (AE)
 - Passive technique where micro and macro fracture events are monitored during the fatigue test
- Guided Plate Wave Time of Flight from Pulsed Waves
 - Active technique – uses pulsed waves to measure speed of sound – used to determine a damage parameter

Experimental Approach

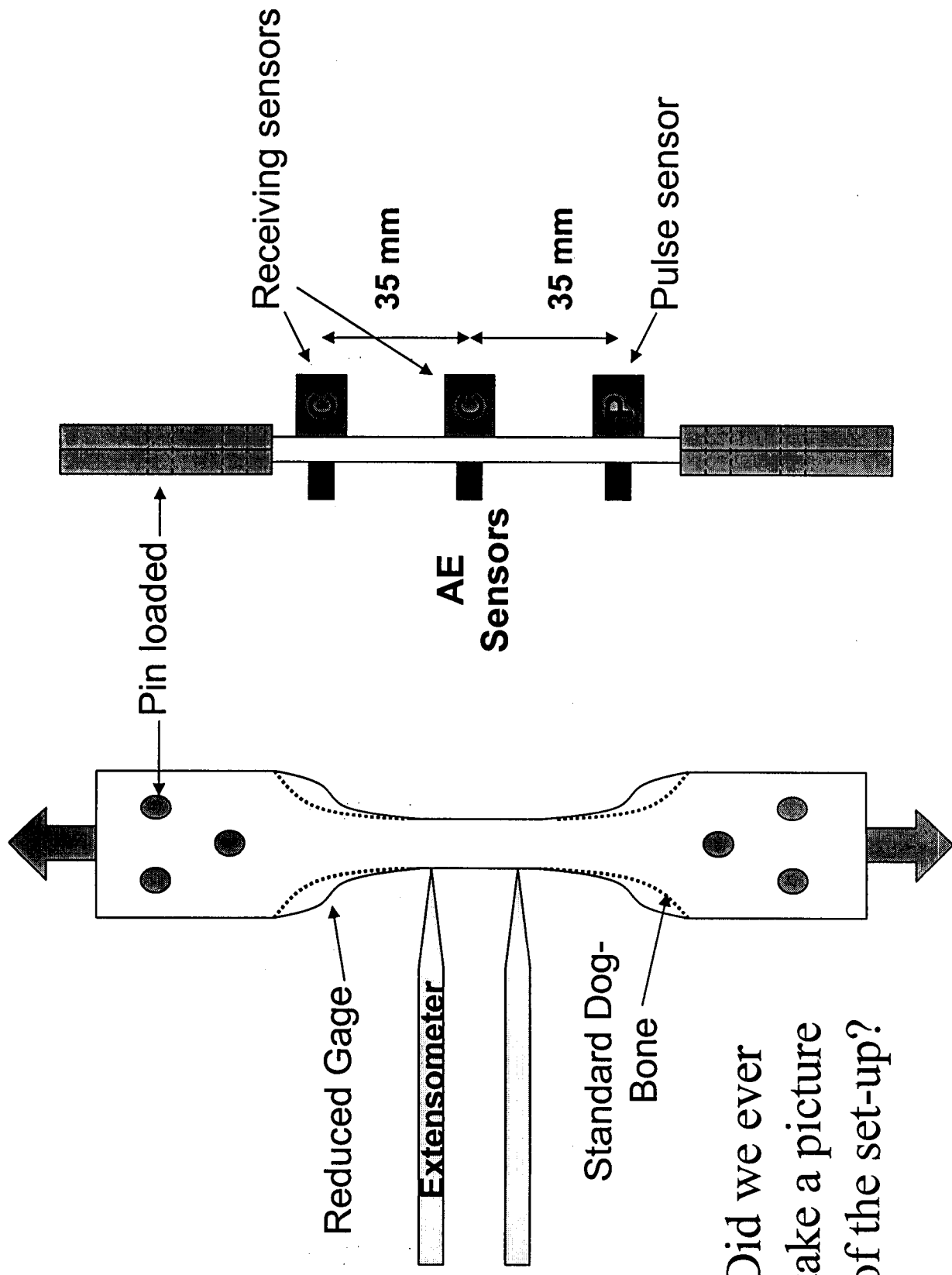
- Perform fatigue experiments* at relatively high frequency and R-ratio similar to Life-Prediction test-matrix
- Increase severity of fatigue to cause failure, i.e., Increase peak stress and decrease R-ratio
- Compare fatigue conditions and acoustic response for specimens that failed with those that do not

* All fatigue experiments performed at SRI

Experimental Procedure

- 2 types of composites tested:
 - T300 fibers; C interphase; CVI SiC or MI matrix
- Fatigue conditions
 - Peak stress = 40 to 60 ksi
 - $R = 0.85$ or 0.1
 - $f = 10$ Hz
- AE monitoring
 - Wide-band pass sensors = 100 to 2,000 kHz
 - Fracture Wave Detector, Digital Wave Corporation
- Interrupted after certain # cycles for guided plate wave time of flight measurement

Test Specimen Configuration

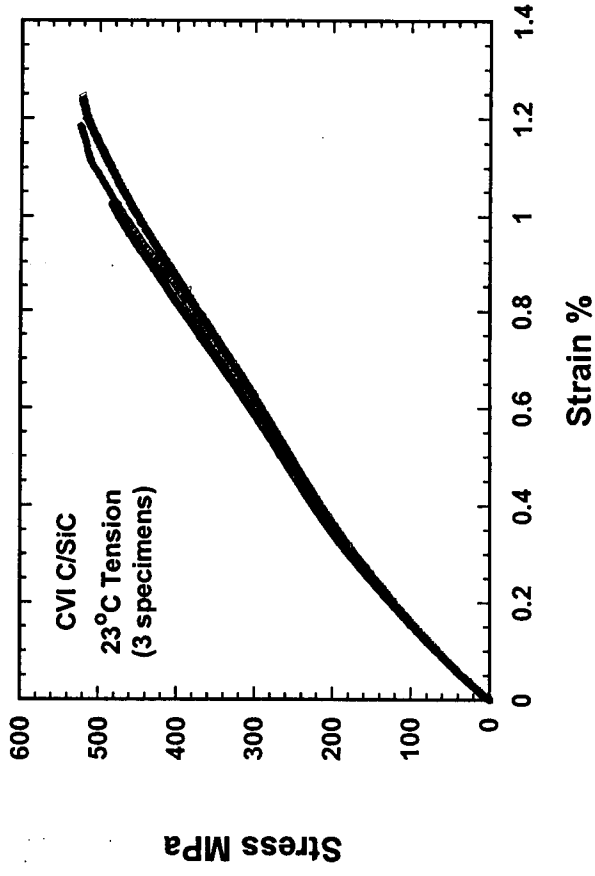


Did we ever
take a picture
of the set-up?

Monotonic Stress-Strain

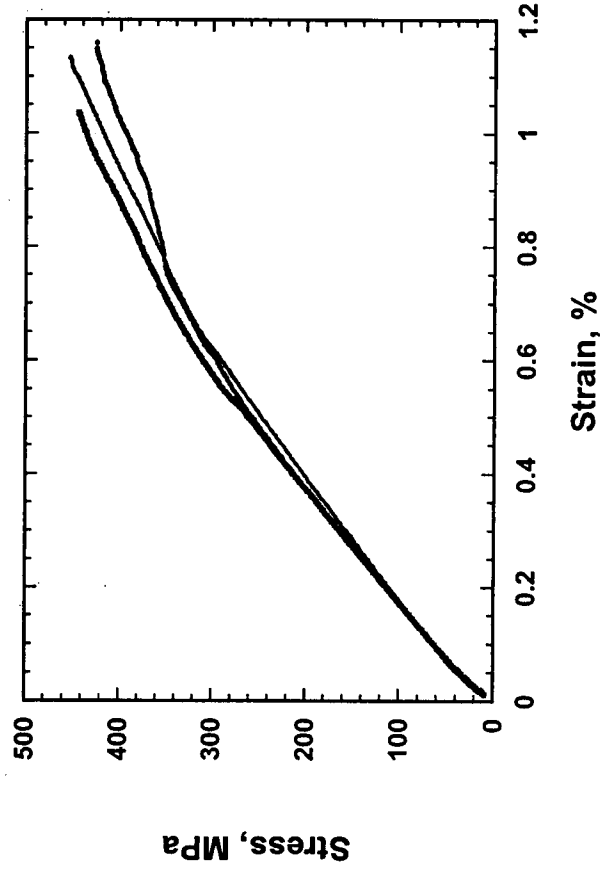
CVI SiC Matrix

Avg $\sigma = 74.2$ ksi (511 MPa)
 $E = 11.3$ Msi (78 GPa)



MI SiC Matrix

Avg $\sigma = 64.2$ ksi (442 MPa)
 $E = 10.9$ msi (75 GPa)



Experimental Results

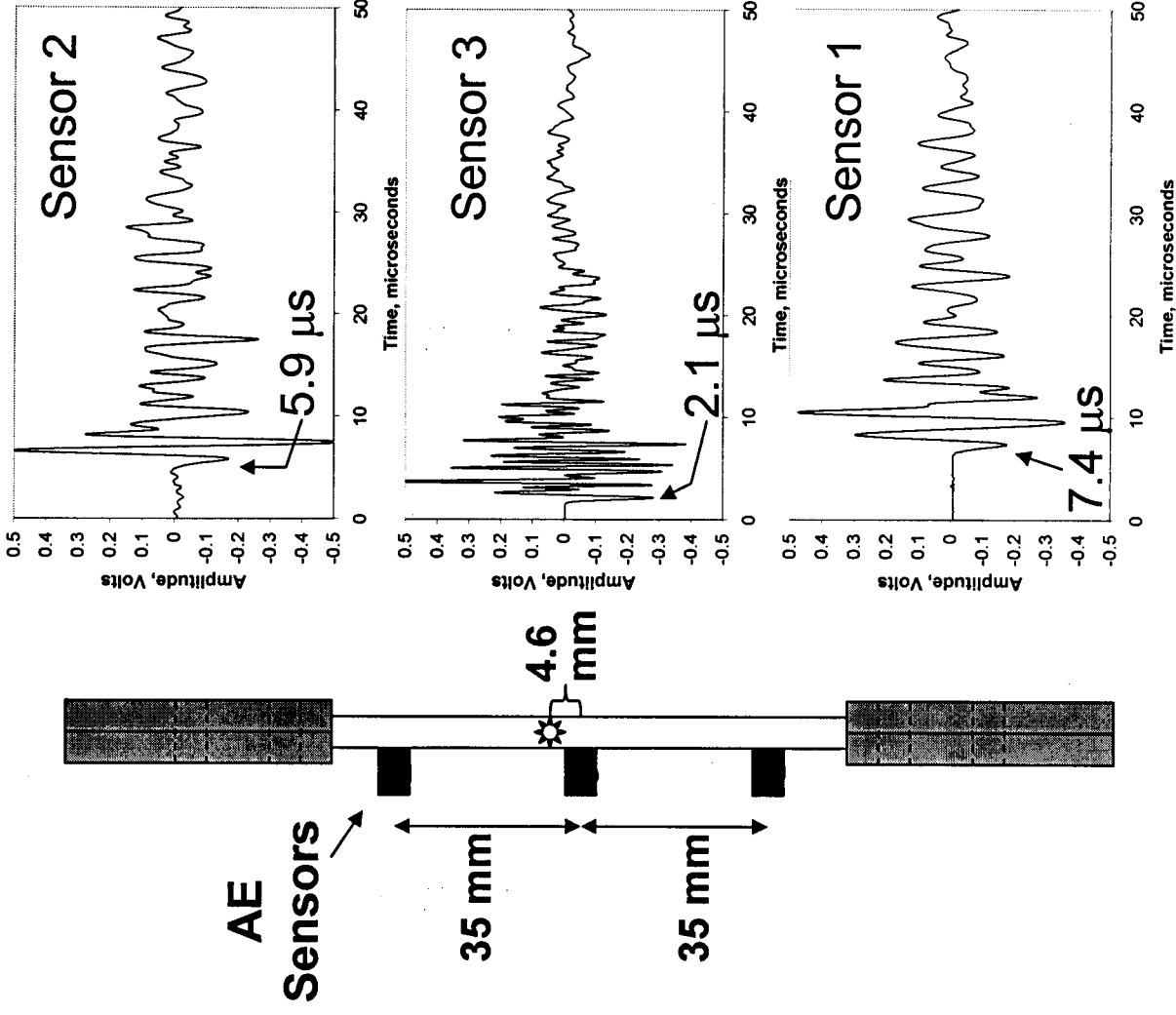
Specimen configuration	Peak stress, ksi	R	Cycles to failure	Retained strength, ksi
CVI SiC Matrix				
Reduced gage	40	0.85	100,000 (Run Out)	70.4
Reduced gage	60	0.85	100,000 (Run Out)	69.7
Normal dog-bone	60	0.1	28,364	--
MI SiC-Si Matrix				
Reduced gage	40	0.85	100,000 (Run Out)	55.8
Reduced gage	50	0.85	100,000 (Run Out)	55.6
Normal dog-bone	50	0.1	100,000 (Run Out)	58.2
Normal dog-bone	55	0.1	37,018	--

Modal AE Description

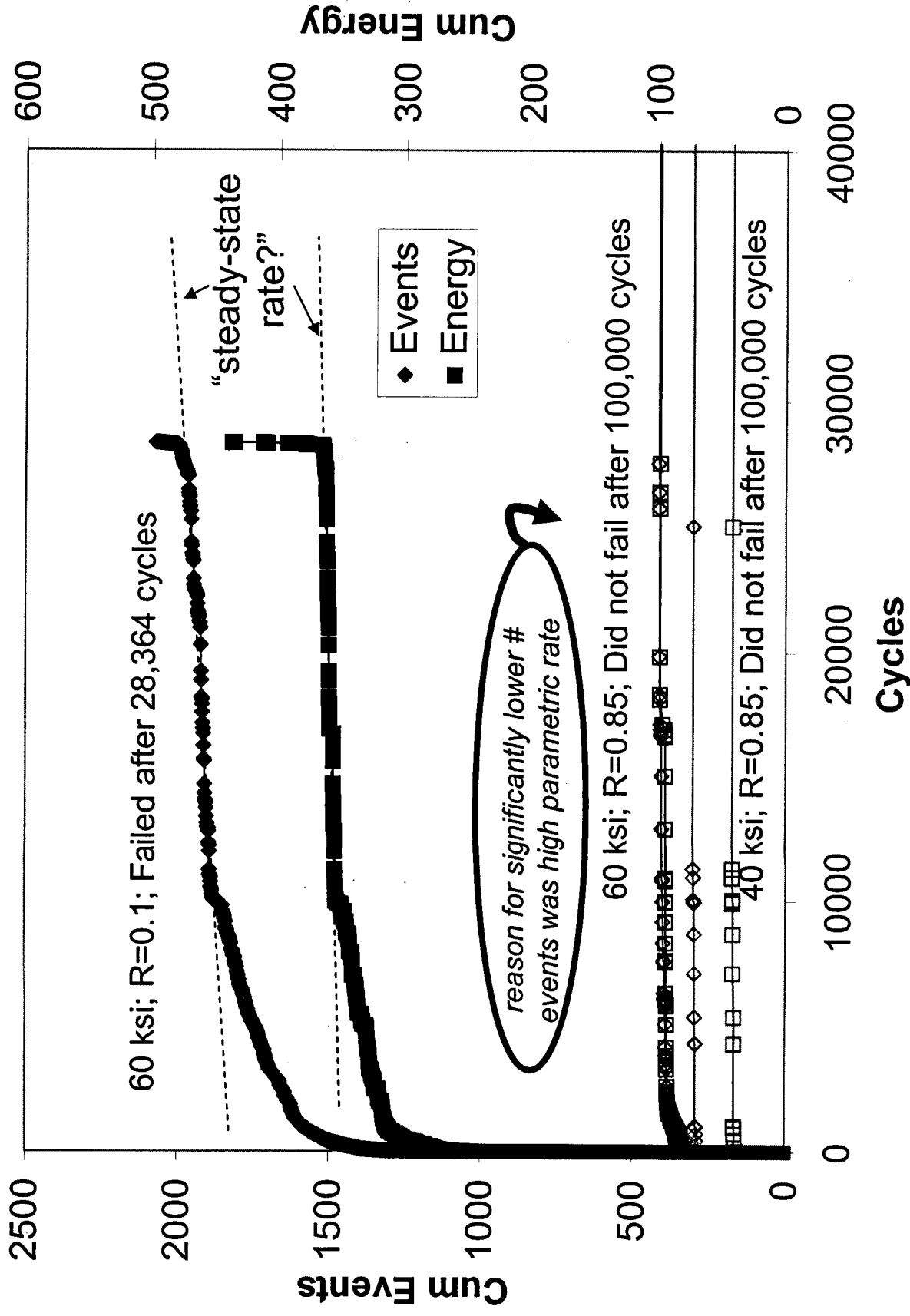
AE is monitored during the fatigue test

Data is sorted according to which sensor was triggered first → data for first-trigger on sensor 3 is analyzed (gauge events) for rate of AE activity

Location determined from difference in time of arrival for events near failure (waveforms correspond to an event which occurred just prior to fatigue failure for M1 specimen – cycle 36,951)



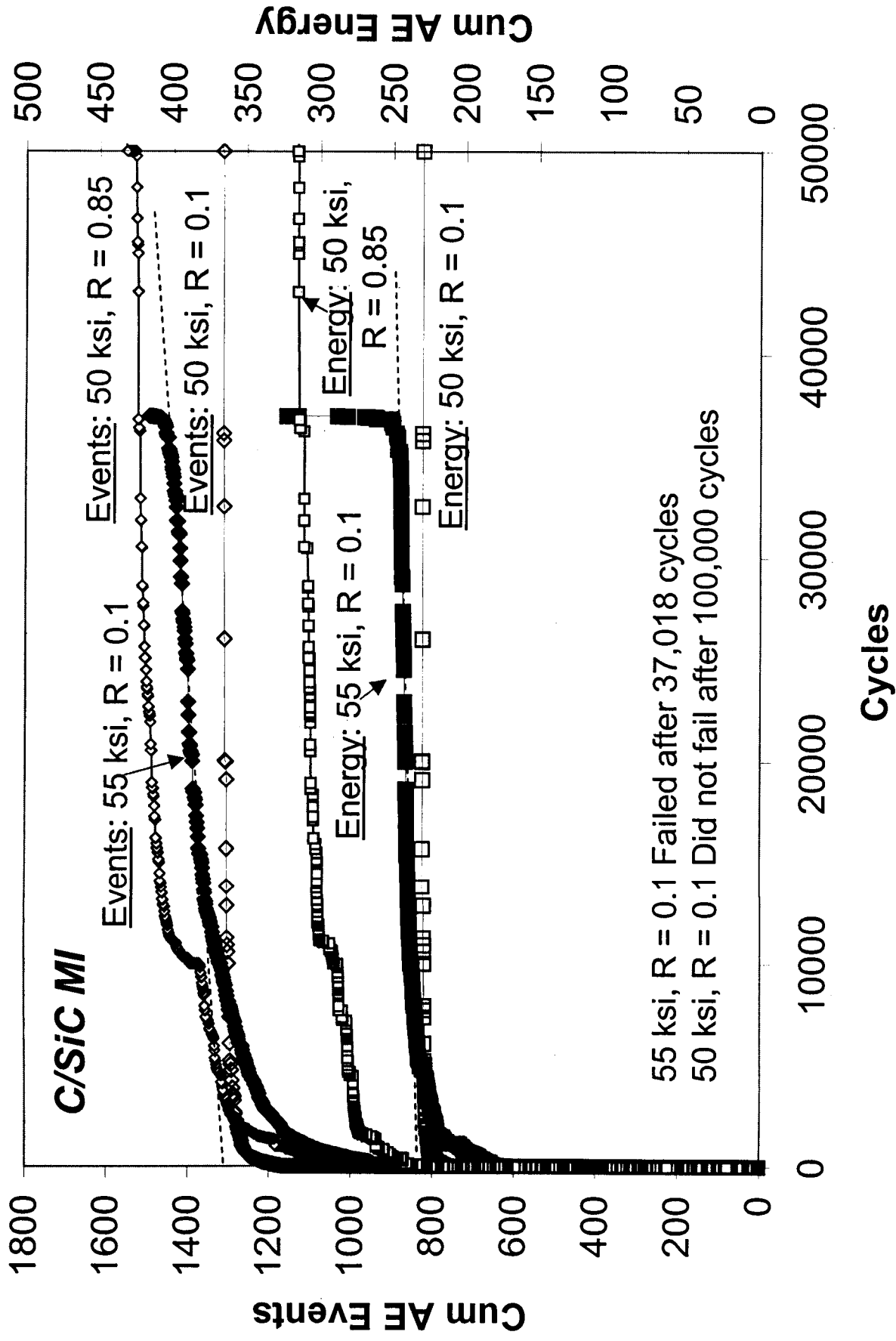
AE Results: CVI SiC



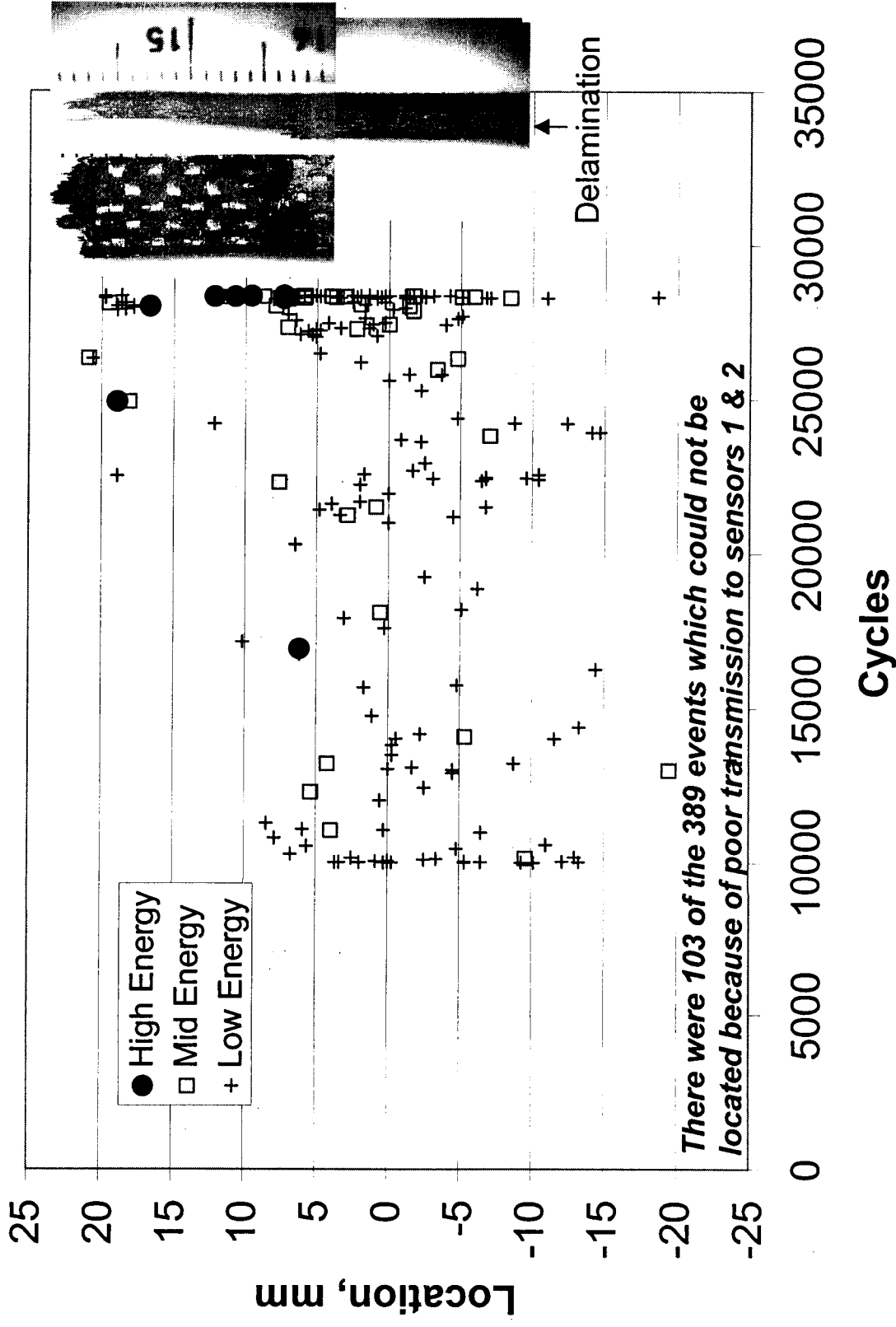
AE Results: Analysis

- Most AE occurs on 1st loading cycle
- For specimens that did not fail: AE tapers off to negligible increase after 10,000 cycles
- For specimens that did fail: AE events and energy increase at a relatively steady-state rate, albeit slight, until failure where the rate increases (“tertiary” appearance)

AE Results: MI SiC-Si



Location of AE for CVI SiC Composite that Failed: cycles 10,000 to 28,364



Location of AE and Fatigue

Failure: Analysis

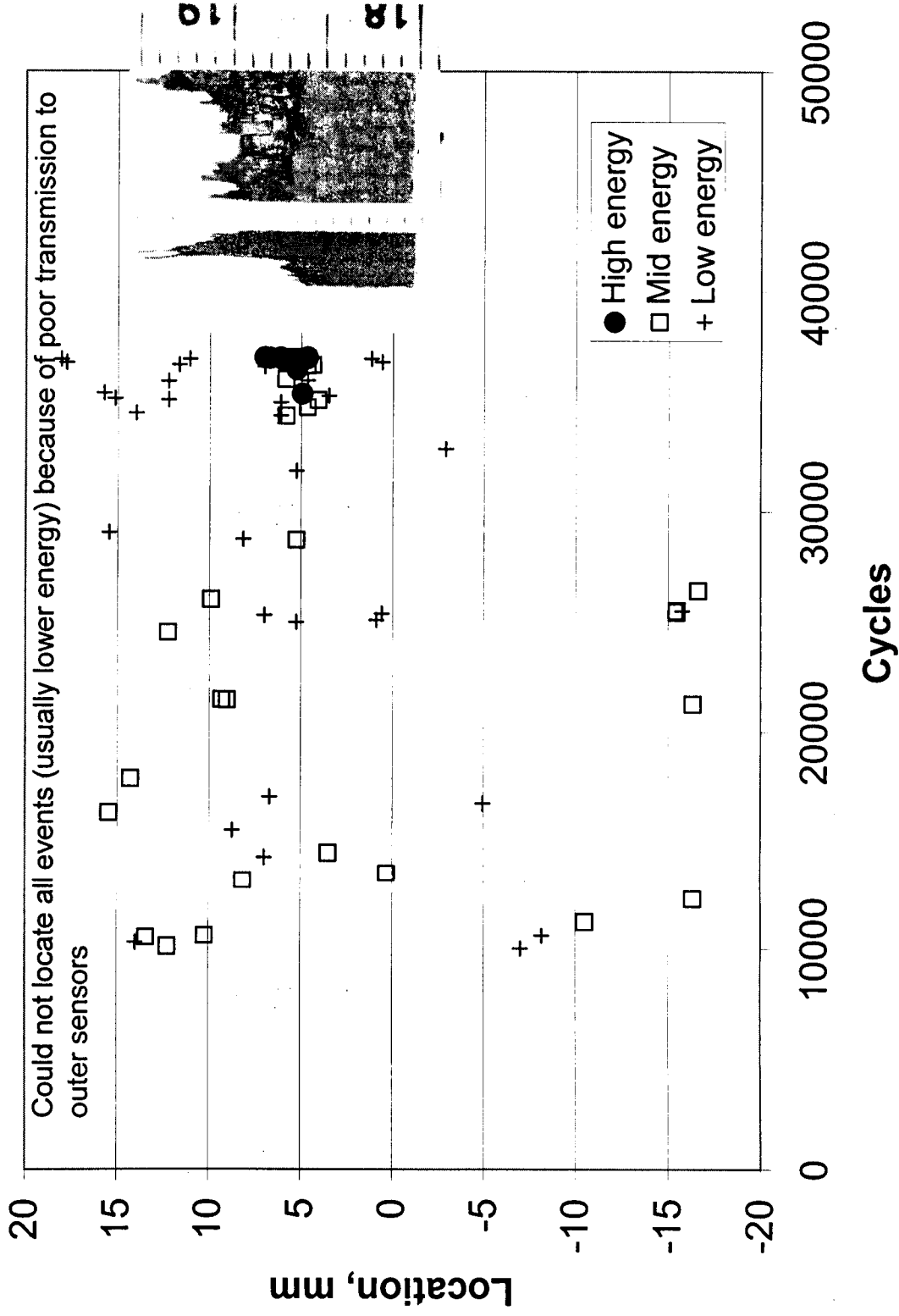
- “0” = center of gage
- Location only determined for cycles $> 10,000$
- Fracture surfaces shown in appropriate location

***AE could easily locate where failure occurred
(high energy events in last few cycles)***

***However, not straight-forward to identify
eventual location early in test***

**** Many events could not be located accurately
due to poor transmission to far sensors or
background noise.***

Location of AE for MI SiC Composite
that Failed: cycles 10,000 to 37,018



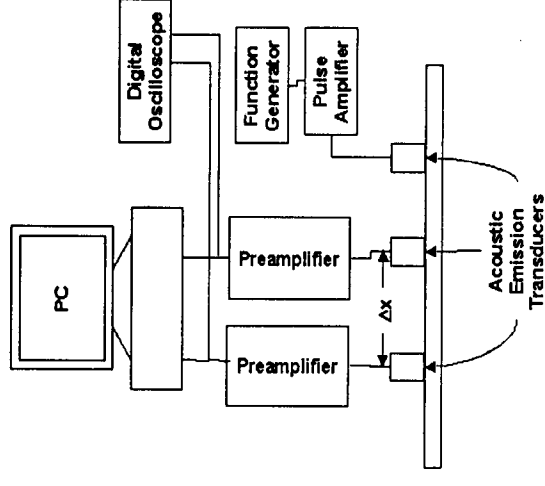
Guided Plate Wave Time of Flight Description

Approach

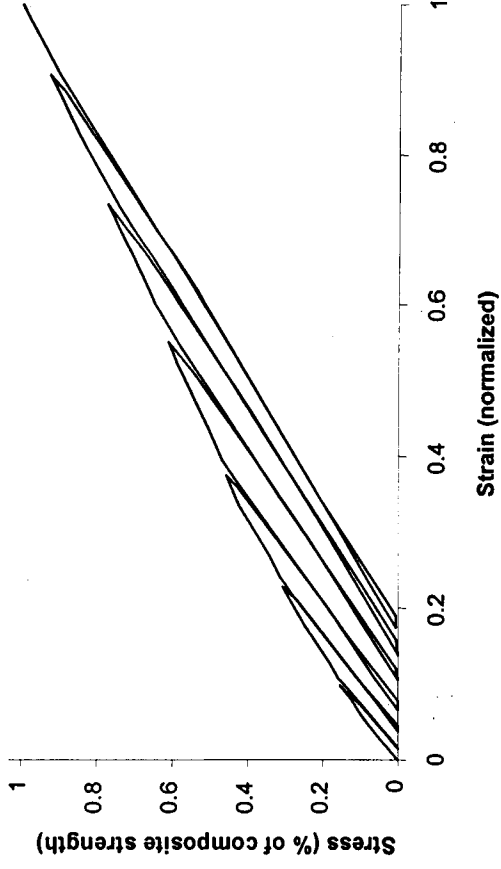
- Damage defined : $D = 1 - E/E_0$
- Nondestructively determine initial and instantaneous elastic modulus
- Guided plate wave velocity
 - Elastic modulus is function of time of flight squared (i.e. $D = 1 - \Delta t_0^2 / \Delta t^2$)
 - Propagates in lateral direction
 - Displacement throughout wall thickness
 - Isolate modes to determine individual mode velocities by windowing

Experimental Setup

- GPW Excitation - narrow band 140 kHz AE transducer driven with a 500 ns, 10 V square wave pulse amplified to 82V
- GPW Detection -two narrow band 140 kHz AE transducers, separated by 35 mm.
- Processing -Voltage amplified with a 40 dB gain, digitized to 16-bit precision at a sampling rate of 20 MHz

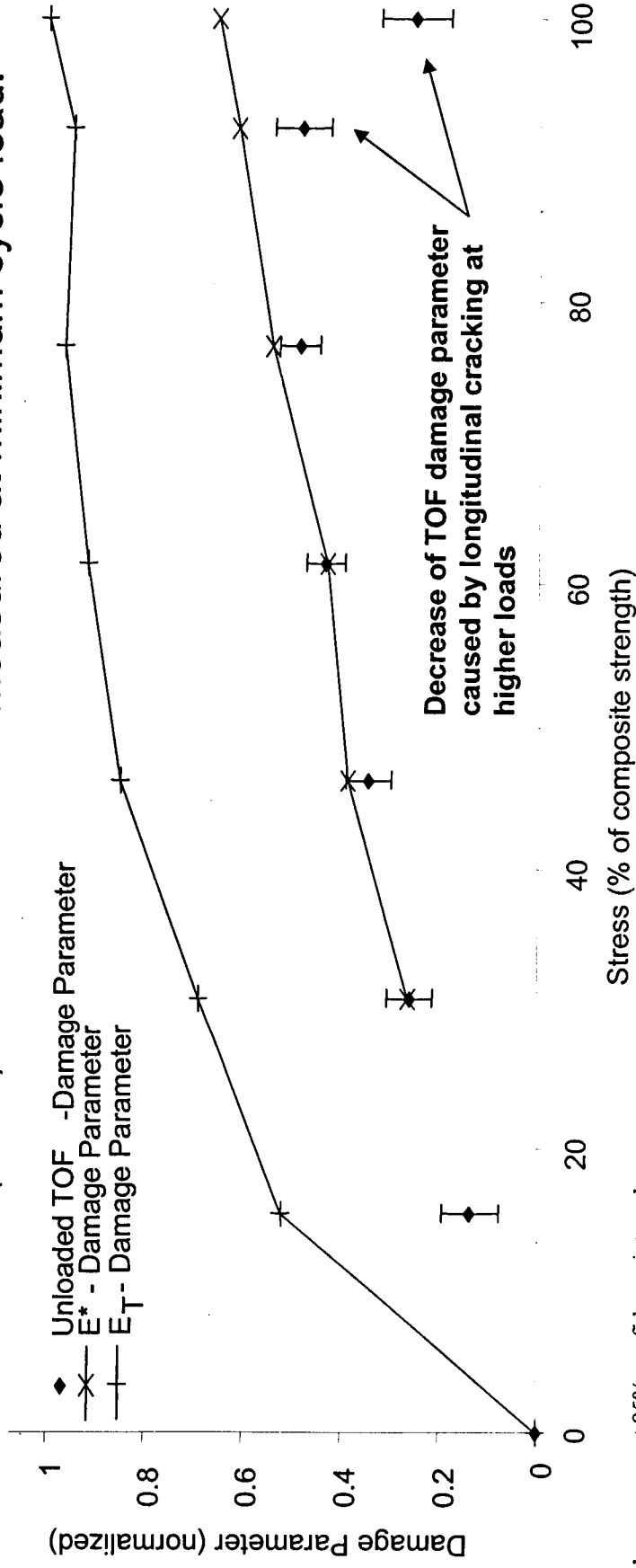


Guided Plate Wave Results: CVI SiC Tensile Loading



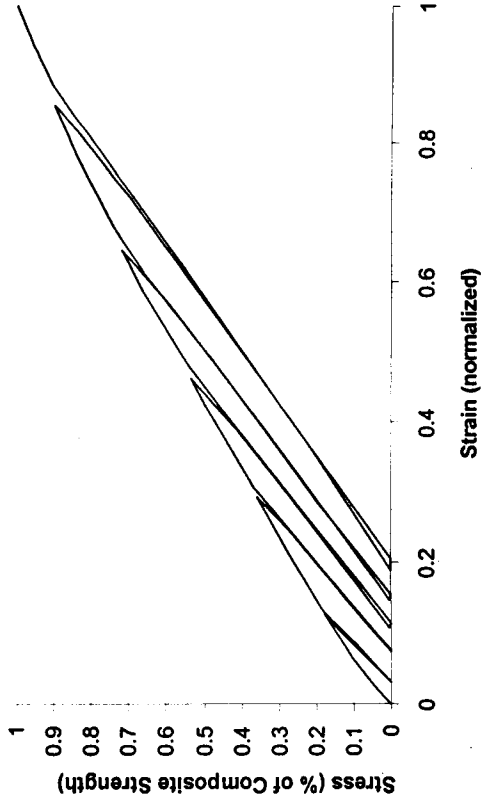
Load/unload tensile loading

- E^* - damage parameter computed from minimum cycle load.
- E_T - damage parameter computed from maximum cycle load.
- TOF - damage parameter computed from guided plate wave time of flight measured at minimum cycle load.



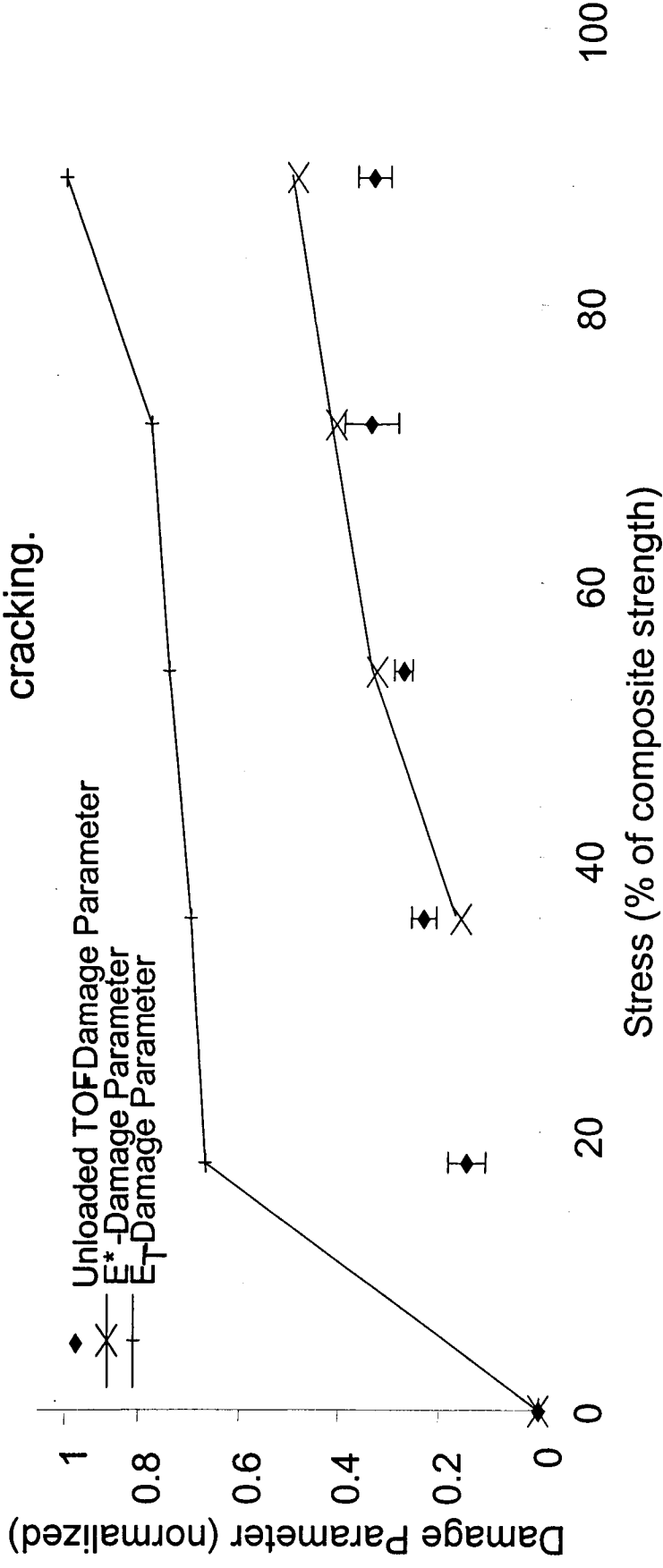
Error bars represent 95% confidence interval

Guided Plate Wave Results: MI SiC-Si Tensile Loading



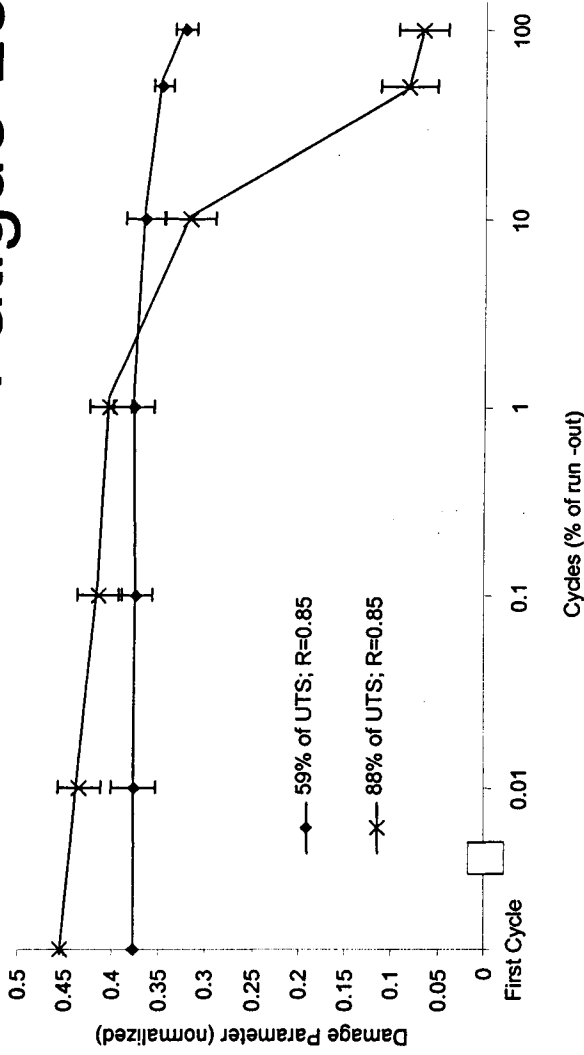
Load/unload tensile loading

- E^* - damage parameter and E_T - damage parameter have similar trend as CVI SiC material.
- TOF - damage parameter does not decrease as dramatically as in CVI SiC material indicating less longitudinal cracking.



Error bars represent 95% confidence interval

Guided Plate Wave Results: CVI SiC Cyclic Fatigue Loading



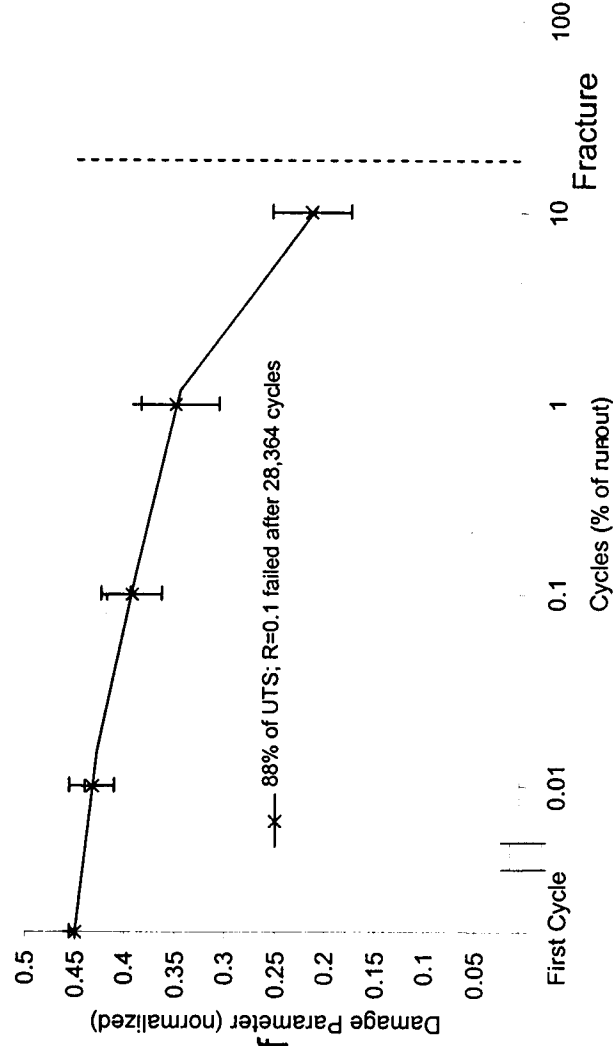
- Both samples cycled at $R = 0.85$.
- Sample cycled at 59% of UTS showed little change in TOF - damage parameter due to cyclic loading.
- Sample cycled at 88% of UTS showed dramatic decrease in TOF - damage parameter indicating propagation of longitudinal cracks.

R = 0.10

- Cycling at $R=0.10$ caused the TOF damage parameter to decrease at a higher rate than the sample cycles at $R=0.85$ for a maximum cycling stress of 88% of UTS.
- No significant change in TOF- damage parameter immediately prior to failure.

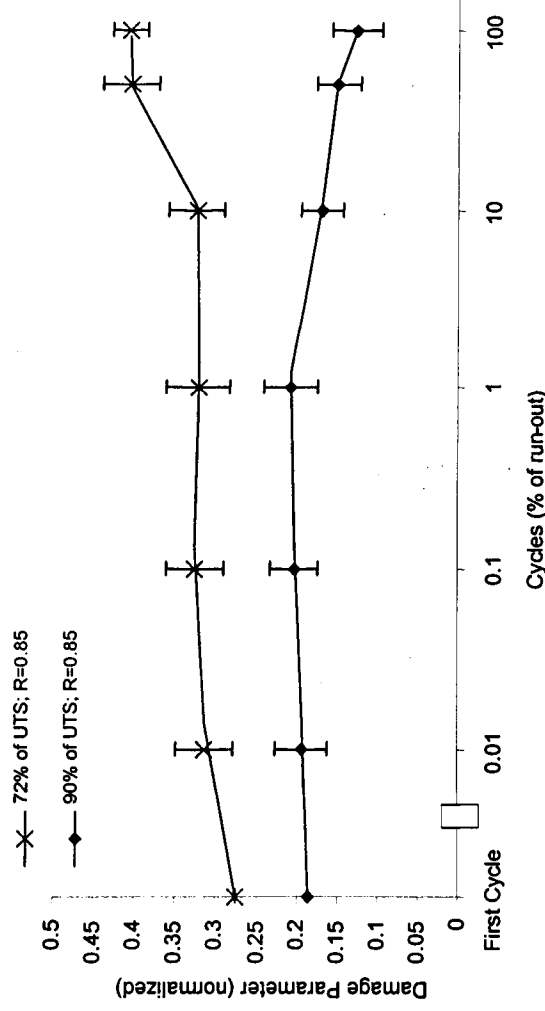
Error bars represent 95% confidence interval

All TOF- damage parameter values have been normalized with respect to the maximum E_T - damage parameter



Guided Plate Wave Results: MI SiC-Si Cyclic Fatigue

Loading

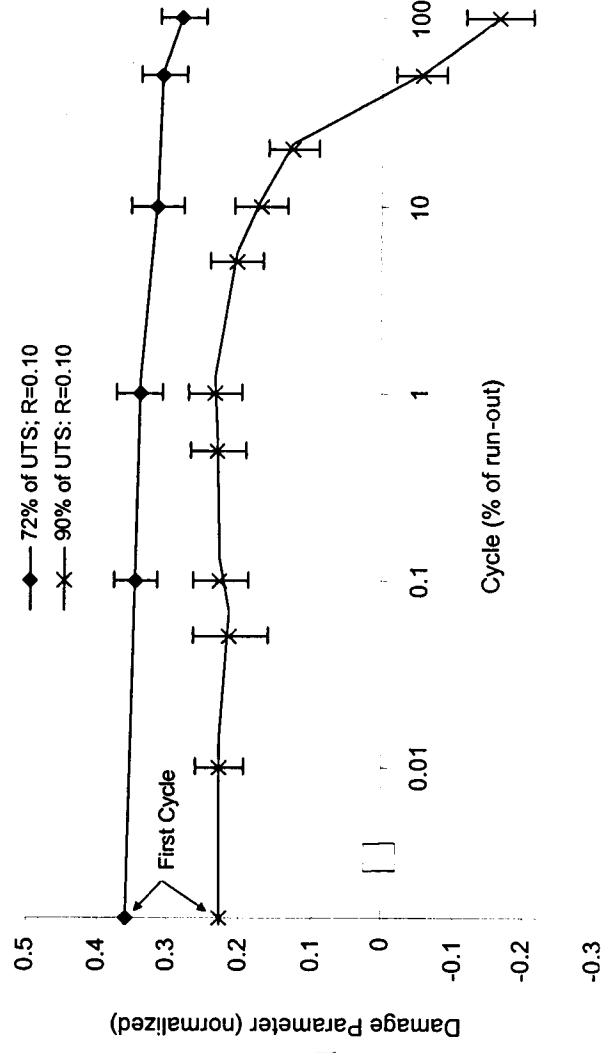


$R = 0.85$

- Sample cycled at 72% of UTS showed an increase in TOF - damage parameter due to cyclic loading
- Sample cycled at 90% of UTS showed slight decrease in TOF - damage parameter indicating propagation of longitudinal cracks

$R = 0.10$

- Cycling at $R=0.10$ caused the TOF damage parameter of the specimen cycled at 72% of UTS decrease slightly
- TOF damage parameter of the specimen cycled at 72% of UTS at $R=0.1$ to decrease significantly leading to a negative damage parameter value (indicating massive amount of longitudinal cracking)



Error bars represent 95% confidence interval

All TOF- damage parameter values have been normalized with respect to the maximum E_T - damage parameter

Guided Plate Wave Time of Flight: Analysis

- Guided plate wave time of flight values highly dependent on matrix cracking
 - Increases with transverse cracking
 - Decreases with longitudinal cracking
- Insensitive to fiber wear caused by matrix fiber friction

AE Results: Conclusions

- There appears to be a level of AE activity that does not diminish for specimens that fail in fatigue compared to those that do not
 - Strategic placement of sensors could be utilized around sensitive areas to monitor this type of AE activity if it could be calibrated for failure
- AE was capable of detecting the location of fatigue failure; however, it was only just a few minutes prior to failure when higher energy events were occurring
 - This was complicated by the fact that transmission of AE waves was not always sufficient to sensors far from the location of failure making it difficult to accurately locate events which may have been helpful earlier in the test
 - This is an artifact of C-SiC material, it would be expected for SiC/SiC that AE transmission would be better

Guided Plate Wave Time of Flight: Conclusions

- Tensile Loading
 - Unloaded TOF – damage parameter correlates well with E^* - damage parameter for low to mid stress levels indicating that the TOF - damage parameter is sensitive to transverse matrix cracking
 - At stress levels near fracture stresses, the TOF- damage parameter decreases because of the influence of cracking in the longitudinal direction.
- Tension-Tension Cyclic Loading
 - Room Temperature
 - The low sensitivity of guided plate wave velocity to fiber wear indicates that this technique is not suited to life prediction of materials subjected to room temperature tensile loading.
 - High Temperature
 - For high temperature application - where the life of the component is dictated by matrix cracking, environmental oxidation, and fiber wear - guided plate wave time of flight value can become an integral part in estimating residual life because of its high sensitivity to both transverse and longitudinal matrix cracking.